


Fractal Dimension Algorithm for Detecting Oil Spills Using RADARSAT-1 SAR

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Abstract. This paper introduces a method for modification of the formula of the fractal box counting dimension. The method is based on the utilization of the probability distribution formula in the fractal box count. The purpose of this method is to use it for the discrimination of oil spill areas from the surrounding features e.g., sea surface and look-alikes in RADARSAT-1 SAR data. The result shows that the new formula of the fractal box counting dimension is able to discriminate between oil spills and look-alike areas. The low wind area has the highest fractal dimension peak of 2.9, as compared to the oil slick and the surrounding rough sea. The maximum error standard deviation of low wind area is 0.68 which performs with fractal dimension value of 2.9.

Keywords: Fractal algorithm, Probability Density Function (PDF), RADARSAT-1 SAR image, oil spill, look-alikes.

1 Introduction

Fractal geometry can be used on occasion to discriminate between different textures. A fractal refers to entities, especially sets of pixels, which display a degree of self-similarity at different scales. Self-similarity is the foundation for fractal analysis and is defined as a property of a curve or surface where each part is indistinguishable from the whole, or where the form of the curve or surface is invariant with respect to scales, meaning that the curve or surface is made of copies of itself at reduced scale and enlarged scales [9].

The most well known procedures that have been proposed for estimating the fractal dimension of SAR images are box counting, fractal Brownian motion [1],[14] and fractal interpolation function system dimension of images [4]. Initially, Falconer [8] introduced the fractional Brownian motion model with SAR image intensity variation, which has shown promise in the SAR data textures. In fact, both the sea surface and its backscattered signal in the SAR data can be modeled as fractals [8],[19].

By contrast, Gado and Redondo [10] found that a box counting fractal dimension model provided excellent discrimination between oil spills and look-alikes, although

the backscatter information, which could allow a first robust localization of the oil spills, had not been considered. Furthermore, Benelli and Garzelli [3] used a multi-resolution algorithm which was based on fractal geometry for texture analysis. They found that the sea surface is characterized by an approximately steady value of fractal dimension, while the oil spills have a different average fractal dimension compared to look-alikes.

This work has hypothesized that the dark spot areas (oil slick or look-alike pixels) and its surrounding backscattered environmental signals in the SAR data can be modeled as fractals. In this context, a box-counting fractal estimator can be used as a semiautomatic tool to discriminate between oil spills, look-alikes and surrounding sea surface waters. In addition, utilization of a probability density formula in the box-counting equation can improve the accuracy of discrimination between oil slick pixels and surrounding feature pixels such as ocean surface and look-alikes.

2 Fractal Algorithm for the Oil Spill Identification

The oil slick detection tool uses fractal algorithms to detect the self-similar characteristics of RADARSAT-1 SAR image intensity variations. A box-counting algorithm introduced by Benelli and Garzelli [2] was used in this study. The box counting estimator of fractal dimension divided a convoluted line of slick, which was embedded in the image plane, into smaller and smaller boxes by dividing the initial length of the convoluted line at backscatter level β_s by the recurrence level of the iteration [18]. We define a decreasing sequence of backscattering β_s tending from β_0 , the largest value, to less than or equal to zero. The fractal dimension D (β_s) as a function of the RADARSAT-1 SAR image intensity β_s is given by:

$$D(\beta_s) = D_B = \lim_{s \rightarrow \infty} \frac{\log M(\beta_s)}{-\log(\beta_s)} \quad (1)$$

where, $M(\beta_s)$ denotes the number of boxes which are needed to cover the various slick areas with different backscatter intensity β_s in the RADARSAT-1 SAR image. The number of boxes was calculated from the fractal dimension algorithm having side length l_s , and needed to cover a fractal profile, varies as β_s^{-D} , where D is the fractal dimension that is to be estimated. If the profile being sampled is a fractal object, then $M(\beta_s)$ should be proportional to β_s^{-D} , i.e., the following relation, which was adopted from Milan et al. [16], should be satisfied:

$$M(\beta_s) = C\beta_s^{-D} \quad (2)$$

where C is a positive constant derived from a linear regression analysis between $\log M(\beta_s)$ and $\log(\beta_s)$. For different box sizes (β_s), a number of points were

produced in the log-log plane. The dimension $D(\beta_s) = D_B$ can be estimated from a linear regression of these points [16].

In practice it is difficult to compute $D(\beta_s)$ using equation (1) due to the discrete RADARSAT-1 SAR images surfaces, and so approximations to this relationship are employed. First, the RADARSAT-1 SAR intensity image is treated as a two-dimensional matrix $(\beta \times \beta)$. This $\beta \times \beta$ intensity image matrix has been divided into overlapping or abutted windows of size $l_s \times l_s$. For each window, there is a column of accumulated boxes, each box with size of $l_s^2 \times l$. The backscatter values (β_0) are stored at each intersection of the column i and row j of the various slick areas. Then l is calculated by using the differential box counting proposed by Sarkar and Chaudhuri [17]

$$\left[\frac{\beta_s}{l} \right] = \left[\frac{\beta}{l_s} \right] \quad (3)$$

Let the minimum and maximum (β_s) in the (i, j) window fall in boxes numbered n and m . The total number of boxes needed to cover the various slick pixels in the RADARSAT-1 SAR image with the box size $l_s^2 \times l$ is:

$$M(\beta_s) = \sum_{i,j}^l n(\beta_0) - m(\beta_s) + 1 \quad (4)$$

Let $P[M(\beta_s), l_s]$ be the probability of the total number of box $M(\beta_s)$ with box sizes l_s . This probability should be directly proportional to the number of boxes

$\sum_{i,j}^l n(\beta_0) - m(\beta_s) + 1$ spanned on the (i, j) windows. By using equation (4) the expected number of boxes with size l_s which is needed to cover the slick pixels can be calculated using the following formula:

$$M(\beta_s) = \sum_{i,j} \frac{1}{n} P[M(\beta_s), l_s] \quad (5)$$

According to Fiscella et al.[7], the probability distribution of the dark area belonging to slick pixels can be calculated using the formula below:

$$P[M(\beta_s)] = [1 + \prod_n q_n(M(\beta_s)) / p_n(M(\beta_s))] \quad (6)$$

Let $n = \sum_{i,j}^l n(\beta_0) - m(\beta_s) + 1$, q and p are the probability distribution functions

for look-alike and oil spill pixel areas, respectively. From equations (5), (6) and (1) one can get a new formula for estimating the fractal dimension D_B

$$D(\beta_s) = D_B = \lim_{s \rightarrow \infty} \frac{\log \sum_{i,j} n^{-1} [1 + \prod_n q_n(M(\beta_s)) / p_n(M(\beta_s))]}{-\log(\beta_s)} \quad (7)$$

In practice, the limit of M going to zero cannot be taken as it does not produce a texture image for oil spills or look-alikes in SAR data. Using fractal dimensions to quantize texture for segmentation, we may divide the slick's pixel areas into overlapping sub-images. Each sub-image is centred on the pixel of interest. We then estimate the fractal dimension $D(\beta_s)$ within each sub-image, and assign the fractal dimension value to the central pixel of each sub-image. This will produce a texture image that may be used as an additional feature in slick pixel classification.

3 Results and Discussion

The RADARSAT-1 SAR Standard 2 beam mode (S2) image has been selected for testing the proposed fractal algorithm. The RADARSAT-1 SAR image detail of Fig. 1 contains a confirmed oil-slick which occurred near the west coast of Peninsular Malaysia on 20 December 1999[11]. Fig. 2 shows the variation of the average backscatter intensity along the azimuth direction in the oil-covered area as function of incidence angle for RADARSAT-1 SAR. The backscattered intensity is damped by -10 dB to -18 dB, which is above the RADARSAT-1 noise floor value of nominally -20 dB. The RADARSAT-1 image covered an area located in between $101^\circ 01' 01.01''$ E to $101^\circ 17' 11.5''$ E and $2^\circ 25' 38.6''$ N to $2^\circ 34' 23.5''$ N. This result of backscatter variation across oil spill locations agrees with the study of Maged and Mazlan [15].

The proposed method for estimation of the fractal dimension has been applied to the raw RADARSAT-1 SAR data by using a 10×10 block at full resolution (Figure 4). Figure 4b shows the resulting fractal map. The fractal dimension map shows good discrimination between different textures on the RADARSAT-1 SAR image. The resulting fractal dimension map appears to correlate well with image texture regions (Figs. 3a and 3b). The oil slick pixels are dominated by lower fractal values than look-alikes and surrounding environment (Fig. 3b).

It is interesting to find that the region of oil slick has fractal values are between 1.5 and 2.3 which might be suggested the spreading of oil spill. As well as the fractal dimension value increases, the oil spill becomes more thin which can be noticed in areas of (A to C). In fact, a thick oil spill dampens small scale waves and so there is no Bragg resonance, which reduced the roughness of sea surface compared to thin oil spill [4]. In this context, the fractal dimension is a function of sea surface level

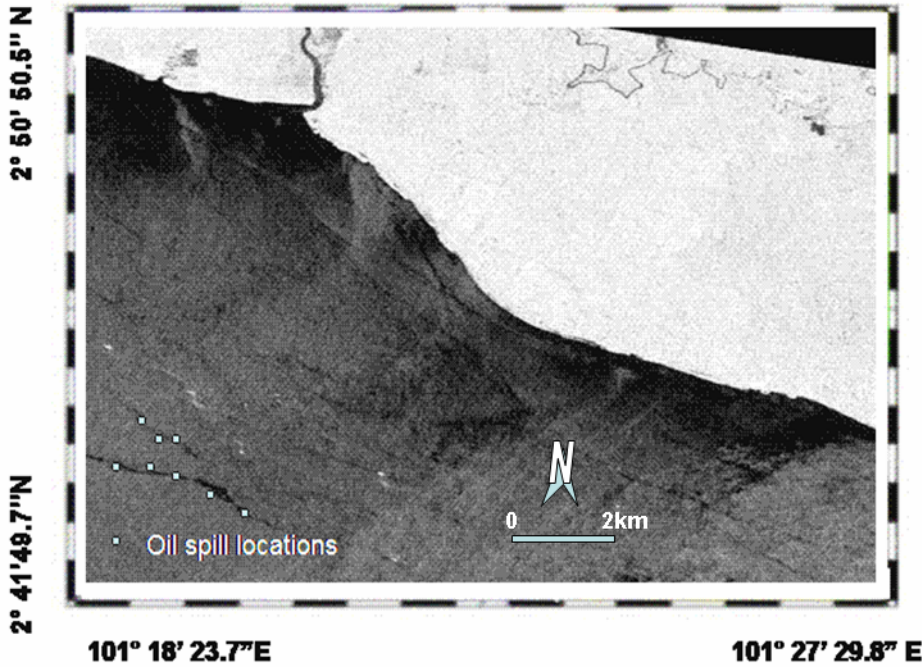


Fig. 1. Locations of oil spill are indicated by small circles

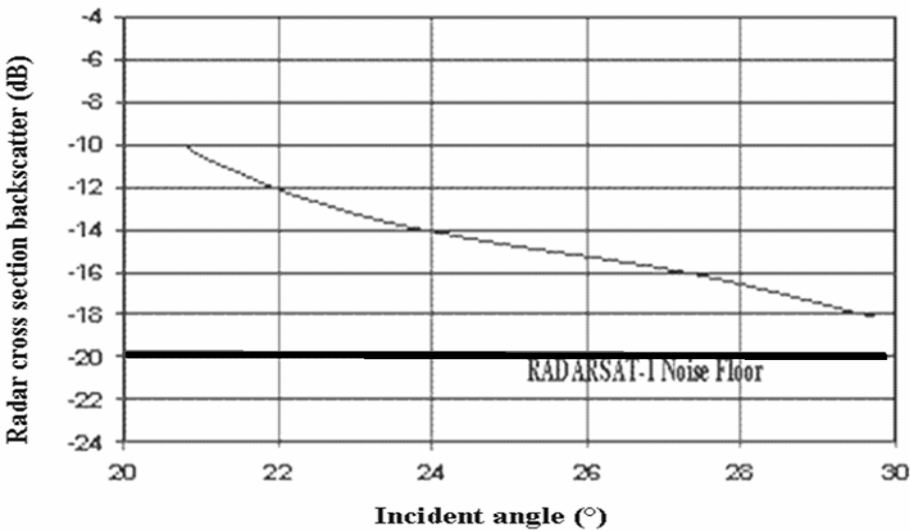


Fig. 2. Radar cross section intensity along oil slick locations

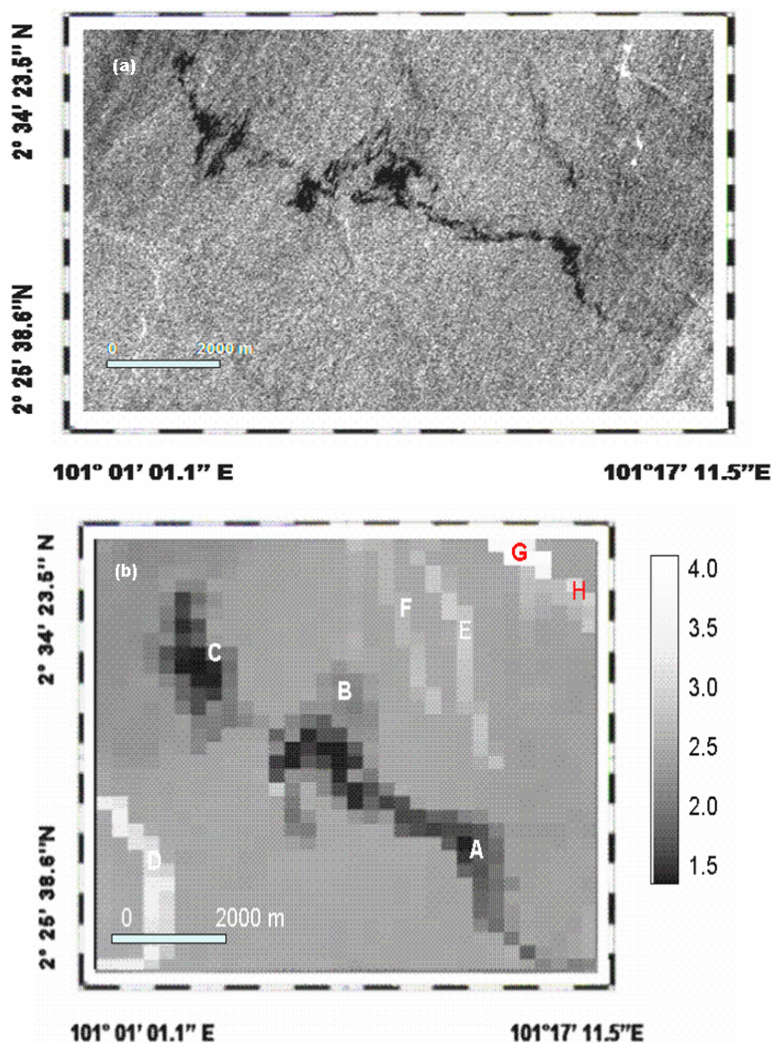


Fig. 3. (a) RADARSAT-1 SAR texture feature of oil spill and (b) fractal map

intensities over the RADARSAT-1 SAR image which expresses the self similarity [12],[17]. The fractal dimension values of look-alikes are between 2.5 and 2.8 which can be seen in the areas F and E. The highest fractal dimension values of 3.4 and 4.0 in the areas D and G are represented the occurrence of shear current flow and existence of ship, respectively. It is interesting to discover that the fractal dimension algorithm based probability is able to extract ship wake information in area H with a value of 3.6. This suggests that the corresponding value of fractal dimension for different categories allows a multi-fractal characterization of the different features in a RADARSAT-1 SAR image. These results confirm the study of Maged and Mazlan[15].

Fig. 4 shows the comparison between oil slick fractal dimension curve and surrounding environment condition curves. The maximum fractal value of 4.0 is observed for a group of ships with normalized backscatter value of 0.9. This suggests that the strong amplitude of variation in RADARSAT-1 SAR image can be mapped as fractal discontinuities and small details are easily detected, *e.g.* ships. This result confirms the study of Maged and Mazlan [15]. Furthermore, it is apparent that the oil spill areas have a parabolic curve with maximum fractal dimension peak value of 2.6 and normalized RADARSAT-1 SAR backscatter value of 0.03 (Fig. 4). It is also found that the sea surface is dominated by a wide steady peak of fractal dimension (Fig. 4), which is 2.7, while the oil spill has substantially different values of fractal dimension, which range between 1.9 and 2.6 (Fig. 4). In fact, the sea surface is considered as a non-fractal object. According to Falconer [9], the slope measure of non-fractal objects corresponds to the complexity of the objects, with the natural implication that the sea surface would have steady value (Fig. 4). By contrast, the look-alike tends to have normal distribution curve with fractal dimension peak of 2.8 and the normalized backscatter is between 0.15 and 0.55; this is distinguishable from the oil slick and the surrounding rough sea (Fig. 4). It can also be seen that there are small differences of 0.2 and 0.3 between the fractal values of the maximum peaks of look-alike, sea surface and oil spill, respectively (Fig.4). This could be attributed to high surface wind speed which was induced sea surface roughness in the RADARSAT-1 SAR image along the surrounding area of the oil slicks and look-alike areas. This was made small differences between the fractal results between oil spills and surrounding sea surface [5],[8],[13].

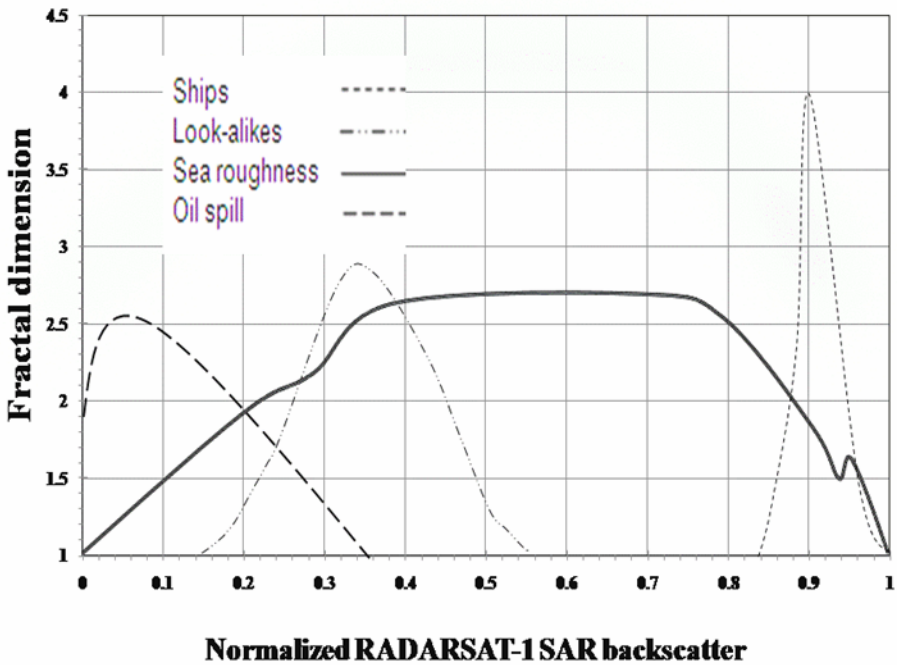


Fig. 4. Fractal dimension curve for different features

4 Conclusions

This study was demonstrated the modification of the fractal box counting formula by involving the parameter of probability density function (PDF). The use of fractal dimension based on the probability distribution function (PDF) improve the discrimination between oil spill, look-alikes, sea roughness and low wind zones. In fact, involving the PDF formula in the fractal dimension map is directly related the textures at different scale to fractal dimension. In addition, this modification of the fractal equation reduces the problems of speckle and sea clutter and assists in the accurate classification of different textures over SAR images.

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